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EVALUATION OF DIRECT DIODE LASER DEPOSITED STAINLESS STEEL 316L ON 4340 STEEL SUBSTRATE FOR AIRCRAFT LANDING GEAR APPLICATION (PREPRINT)

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14. ABSTRACT
300M steel is used extensively for aircraft landing gears because of its high strength, ductility and toughness. However, like other high-strength steels, 300M steel is vulnerable to corrosion fatigue and stress corrosion cracking, which can lead to catastrophic consequences in the landing gear. Stainless steels offer a combination of corrosion, wear, and fatigue properties. But for an aircraft landing gear application a higher surface hardness is required. A laser cladding process with fast heating and cooling rates can improve the surface hardness. AISI 4340 steel is used as a lower cost alternative to 300M due to its similar composition. In this study, the influence of laser cladding process parameters, shield gas, and composition of the deposition and dilution zone has been investigated. The microstructures and composition analysis were evaluated by Scanning Electron Microscopy (SEM) and Optical Microscopy. The deposition hardness varies from 330HV to 600HV.

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Evaluation of Direct Diode Laser Deposited Stainless Steel 316L on 4340 Steel Substrate for Aircraft Landing Gear Application

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300M steel is used extensively for aircraft landing gears because of its high strength, ductility and toughness. However, like other high-strength steels, 300M steel is vulnerable to corrosion fatigue and stress corrosion cracking, which can lead to catastrophic consequences in the landing gear. Stainless steels offer a combination of corrosion, wear, and fatigue properties. But for an aircraft landing gear application a higher surface hardness is required. A laser cladding process with fast heating and cooling rates can improve the surface hardness. AISI 4340 steel is used as a lower cost alternative to 300M due to its similar composition. In this study, the influence of laser cladding process parameters, shield gas, and composition of the deposition and dilution zone has been investigated. The microstructures and composition analysis were evaluated by Scanning Electron Microscopy (SEM) and Optical Microscopy. The deposition hardness varies from 330HV to 600HV.

1. Introduction

Hard chrome plating is a technique that has been the "the gold standard" in commercial production for more than 50 years. It is also a critical process that is used for applying hard coatings to a variety of aircraft components in manufacturing operations. However, hard chromium plating baths contain chromic acid in which the chromium is in the hexavalent state. Hexavalent chromium (hex-Cr) is a known carcinogen having a level of toxicity greater than arsenic or cadmium. So the health risks associated with hard chromium have driven the engineering community in both the military and civilian aerospace sectors, as well as many industrial sectors, to seek alternative coating materials, as well as more cost effective methods to apply them [1].

Among the most promising alternatives are laser cladding coatings. Laser cladding coatings are becoming more industrially viable as lasers have improved dramatically in the past few years, with the production of high power Nd-YAG, CO_2, and diode lasers that are robust and designed for industrial use. The method can be used to weld onto the surface any compatible alloy that can be delivered in wire or powder form. In general the method requires reasonable

access for the laser beam and the feed material, with the laser striking the surface at roughly normal incidence [2].

The cladding process is faster than conventional chrome plating. Typical cladding coatings are applied in one hour, versus 24 hours or more required for hard chrome plating. Another advantage of this process is coating adhesion is excellent due to the metallurgical adhesion, rather than the mechanical bond which High Velocity Oxygen Fuel(HVOF) process produces [3].

Laser cladding tends to be used for high temperature materials. For example, GE Aircraft Engines uses this method for coating the tips of some hot section turbine blades. It is not easy to set up the correct processing parameters, but once they are determined the method can be very robust. This process can produce porosity free deposit more readily than HVOF, which usually produces 2%-5% porosity [3].

The Laser Aided Manufacturing Processes (LAMP) system which was developed at Missouri S&T mainly consists of a 5-axis CNC machining center, a 1.0 KW Diode laser, a powder feeder, and a real–time control system from National Instruments. During deposition, the substrate is fixtured on a 5-axis CNC. The nozzle through which the laser and metal powder is transmitted is fixed to the Z-axis of the CNC. The laser is focused on a small area of the substrate and creates a molten pool, and the metal powder is delivered by the powder feeder system into the molten pool to create the deposition. The X, Y and Z table positions and velocities are regulated via the CNC machining center controller according to the program generated from the CAD model [4]. This hybrid repair system employs a 5-axis positioning system which includes 3 linear axes and 2 rotating axes. The advantage of using this system instead of using the conventional 3-axis positioning system is that it does not require support material to build overhang features for 3D parts. This capability allows both the deposition and machining in a single set-up for a part even with intricate or hidden features. Figure 1 shows the Direct Laser Deposition process.

Fig. 1: Laser Aided Manufacturing Process deposition system

2. Experimental procedure

In the present study, gas atomized 316L stainless steel (purchased from Carpenter Technology) powders of mesh sizes -70+325 was deposited on AISI 4340 steel (Purchased from Rose Metal Products, Inc). Table 1 shows the composition of 316L stainless steel and AISI 4340 steel. A diode laser of wavelength 808 nm (maximum power of 1 kW, spot size of 2.5mm, top hat power profile) was used for materials processing. A single layer fabrication was completed by melting the feedstock powder (delivered by an external powder feeder) using the laser, deposition of the melt on the substrate using an applied power (P) of 700-1000W, scan speed of 10-20 ipm and powder flow rate of 3- 6 g/min, respectively. Fig. 2 shows the deposition results with two different shield gases, nitrogen and argon.

Table 1 Chemical composition range of AISI 4340 steel and 316L stainless steel

Element	C	Mn	P	S	Si	Ni	Cr	Mo	Fe
4340 steel Composition (wt. %)	0.38-0.43	0.6-0.8	0.035	0.035	0.15-0.35	1.65-2.00	0.7-0.9	0.2-0.3	Bal.
316L steel Composition (wt. %)	<0.03%	<2%	<0.045%	<0.03%	<1%	10-14%	16-18.5%	2-3%	Bal.

A cross-section of the deposit and the substrate was prepared to observe the microstructure under the optical microscope (Nikon) and scanning electron microscope (Hitachi, model S570). The samples were etched by a molybdic acid reagent, composed of 100 ml each of HNO_3, HCL, and distilled water with 3 grams molybdic acid. This is a swab etch: A cotton ball was placed in a beaker of etchant and tongs were used to swab the sample surface for approximately 10 seconds. The secondary electron images and EDX data were captured at 10kV accelerating voltage and 15mm working distance [5]. Microhardness of the fabricated layer (from the top surface to the bottom of substrate) was measured using a Vicker's microhardness tester (Struers, Duramin 5) with a 100g applied load.

a. Argon shield gas sample

b. Nitrogen shield gas sample

Fig. 2 AISI 316L stainless steel powder deposited on AISI 4340 steel substrate with argon and nitrogen

3. Results and discussions

Homogeneous and defect free 316L stainless steel coating microstructure has been abstained. Fig. 3 shows the cross-sectional microstructure of laser assisted fabricated 316L stainless steel processed with a laser power of 850W, scan speed of 13.7 ipm and a powder feed rate of 4.5 g/min in both deposition and dilution zone. The coating is dense, adherent and crack-free. The microstructure is mostly cellular, with an average grain size of 10µm. An optical microscopy study shows that the coating microstructure is highly dependent on laser cladding process parameters and under a narrow range of processing parameters a defect free and homogeneous microstructure can be obtained [6].

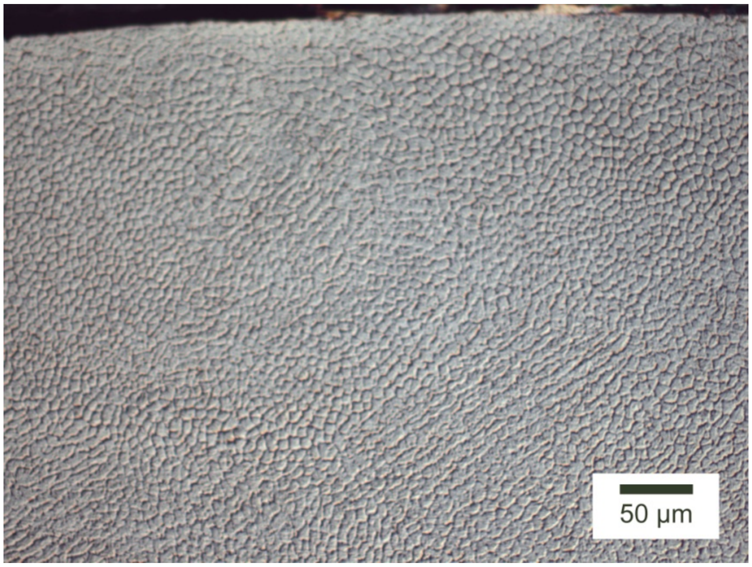

Fig. 3 Homogeneous microstructure of laser fabricated 316L stainless steel on 4340 steel substrate

The microhardness analysis of the fabricated product showed that the average microhardness varied from 330 to 600HV across all the samples in this study. The hardness variation was observed in both the deposit and the dilution area. The hardness measured is significantly higher than the microhardness values reported in previous work with similar materials and process conditions where the microhardness values varied from 150 to 280HV [6]. Fig. 4 illustrates the microhardness trend from the top down (opposite growth direction) for laser assisted fabricated 316L stainless steel on AISI 4340 steel processed with a laser power of 760 W, scan speed of 10 inch/min, and a power flow rate of 3.6 g/min. The behavior shown in Fig. 4 is typical for all samples generated in this study.

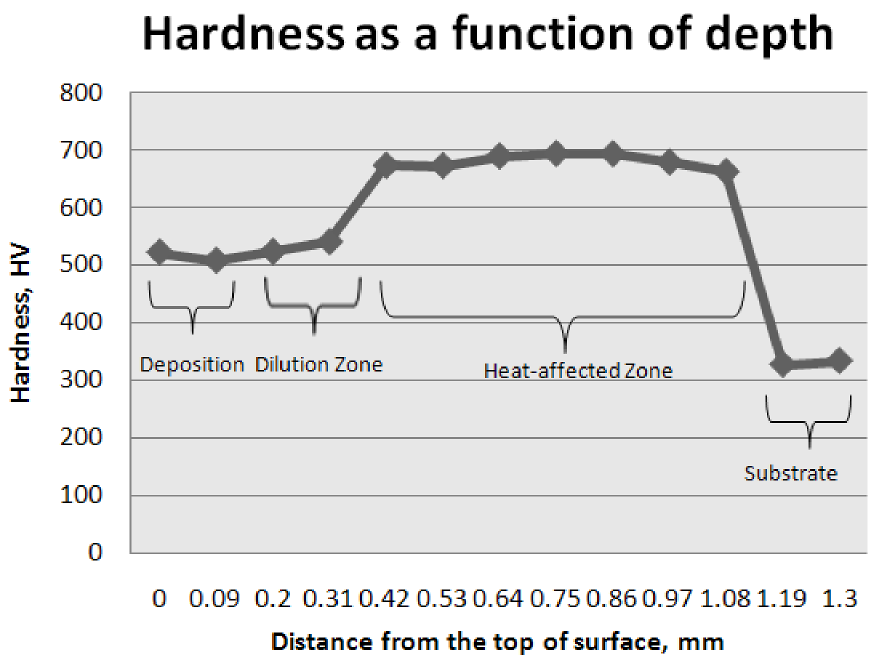

Fig. 4 The trend of microhardness of laser deposited 316L stainless steel on AISI 4340 steel along the direction from the top down (Process parameters: laser power of 760 W, scan speed of 10 inch/min; power flow rate of 3.6 g/min)

Fig. 5 is a quantitative analysis as a function of depth. From Fig. 4 and Fig. 5 we can conclude that the elemental composition of the deposition and the dilution zone are almost the same. Also, the hardness of the deposition and dilution zone is similar. At the bottom of the dilution zone, we can see the sudden composition change as well as the hardness change. The hardness change is because the composition of the dilution zone and heat-affected zone differs. The hardness of the heat-affected zone can reach as high as 600HV, comparing the annealed AISI 4340 steel substrate hardness from 250 HV to 300 HV. In the present study, no significant microhardness as well as microstructural difference between shield gas nitrogen and argon has been found, thus it should be cost effective to use nitrogen as shield gas.

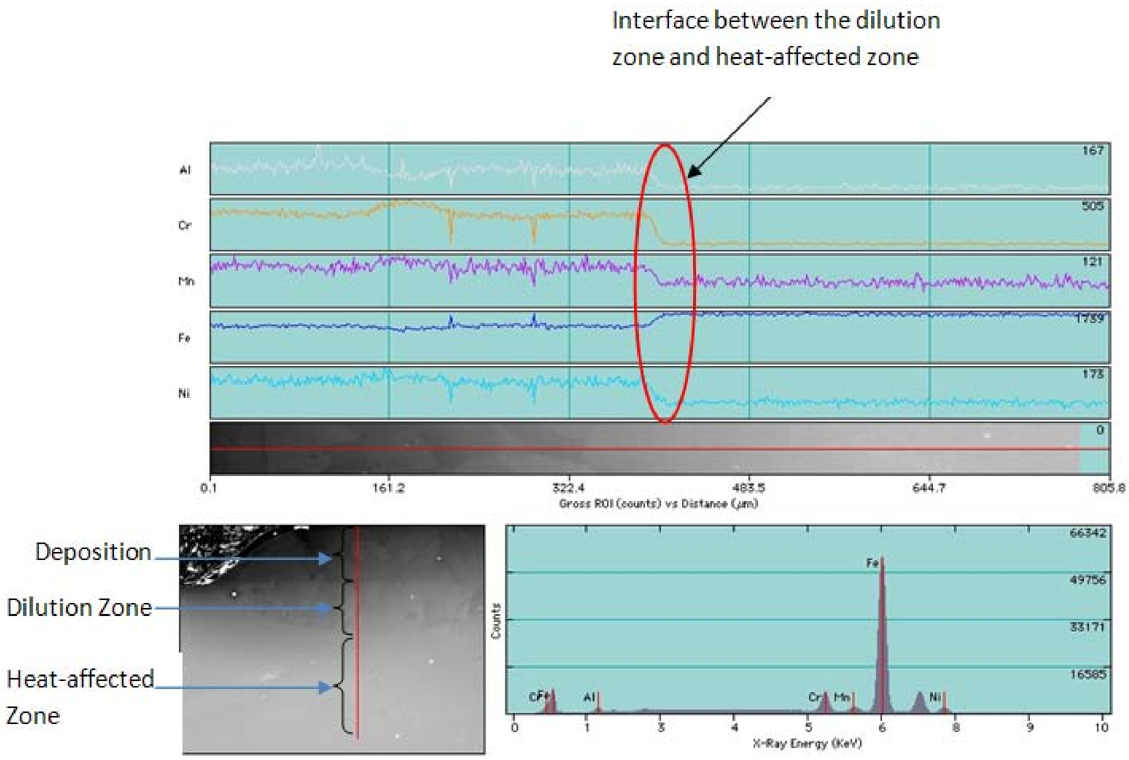

Fig. 5 Quantitative analysis and as a function of depth for laser deposited 316L stainless steel on AISI 4340 steel from the top surface to the bottom of the substrate (Process parameters: laser power of 760W, scan speed of 10 inch/min, power flow rate of 3.6 g/min)

4. Summary and conclusions

In this paper, the microhardness and EDX analysis of laser assisted fabricated AISI 316L stainless steel on the 4340 steel substrate has been studied with the following process condition: laser powder of 700-1000W, scan speed of 10-20 ipm and powder flow rate of 3- 6 g/min.

From the results, the following conclusions could be drawn:

1. The microhardness of the fabricated layer was significantly improved to as high as 330–600 HV as compared to 150 VHN when conventionally processed. The improved microhardness is attributed to grain refinement achieved during laser processing as well as the fast cooling rate during the laser cladding process.
2. No significant microhardness or microstructural difference between shield gas nitrogen and argon has been found, thus it will be cost effective to use nitrogen as shield gas.
3. The elemental composition of the deposition and the dilution zone are almost the same. Also, the hardness of the deposition and dilution zone is similar.

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